Evaluation of stock structure for the Bering Sea/Aleutian Islands shortraker rockfish

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Introduction

In 2009 a Stock Structure Working Group (SSWG), consisting of members of the North Pacific Fisheries Management Council's (NPFMC) Scientific and Statistical Committee (SSC), Groundfish Plan Teams, geneticists, and assessment scientists, was formed to develop a set of guidelines that will help promote a rigorous and consistent procedure for making management decisions on stock structure for Alaska stocks. The committee produced a report, originally presented at the September 2009 meeting of the joint Groundfish Plan Team and updated for the September 2010 meeting (Spencer et al. 2010), which contains a template (Table 1) that identifies various scientific data from which we may infer stock structure. At the November, 2012, meeting of the joint Groundfish Plan Team recommended application of the template to several stocks, including BSAI shortraker rockfish.

The purpose of this document is to use the template produced by the SSWG to evaluate scientific information on stock structure. The SSWG template has a number of broad categories of information relevant to BSAI shortraker rockfish, including spatial harvest patterns, oceanographic characteristics, differences in growth and age/size structure, and genetic information.

Harvest and Trends

The purpose of examination of harvest data and survey population trends is twofold: 1) to evaluate whether fishing mortality is large enough that spatially disproportionate harvesting represents a potential conservation concern; and 2) to identify any differences in populations trends that may indicate demographic independence.

Fishing mortality (relative to target reference point)

Values of fishing mortality much less than the target reference point may indicate an absence of conservation concern with respect to spatially disproportionate harvesting.

The estimates of BSAI-wide fishing mortality for the ten-year period 2002-2012 ranged from 0.009 to 0.021 with a mean of 0.014. The ratio of F to the estimated F_{abc} of 0.0225 from the 2012 assessment ranged from 0.40 to 0.93 during this period, with a mean of 0.64. Although overall fishing rates are below current estimates of reference fishing rates, they are not sufficiently low that conservation concerns regarding spatially disproportionate harvesting patterns could be ruled out without further analysis.

Spatial concentration of harvest relative to abundance

The spatial concentration of harvest relative to abundance was evaluated by calculating area-specific exploitation rates from 2004 to 2012. For each of the Aleutian Island subareas, an exploitation rate for a given year was obtained by dividing the yearly catch by the estimate of biomass for the subarea. The subarea biomass for each year was obtained by partitioning the estimated beginning-year biomass (taken from the stock assessment and/or projection models applied in the fall prior to a given year) into the subareas. A weighted average of the three most recent surveys was applied to each subarea (weights of 4, 6, and 9, with recent surveys higher weights), and the proportions from these averages were used to partition the projected biomass.

The survey biomass estimates of shortraker rockfish follows a gradient, with the highest abundance in the western and central AI (average of 9150 t and 9317 t, respectively, from 1991-2012) and lowest abundance in the southern Bering Sea (SBS) portion of the AI survey (average of 1201 t from 1991-2012) (Figure 1). Shortraker rockfish are also found in the EBS slope survey, with a point estimate of 9299 t in 2012. In the CAI, EAI, and SBS areas, the time series of survey biomass estimates appears to have declined since the early 1990s, although interpretation of these data are hindered by large CVs of the point estimates. The survey coefficients of variation (CV) are lowest in the CAI (average of 0.27 from 1991-2012) and highest in the SBS (0.74 from 1991-2012) (Figure 2). Using the weighted averages of the most recent three surveys indicates that that the estimated proportion in the WAI has declined from 39% to 20% whereas the estimated proportion in the EBS has increased from 11% to 31% over this period, and other areas have been relatively stable (Figure 3).

From 2004- 2012, catches of shortraker rockfish have been highest in the EBS area, averaging 91 t annually, although the catches have declined since a peak value of 174 t in 2010 (Figure 4). Catches from 2004-2010 have been relatively similar in the WAI, CAI, and EAI, with the exception of 2006 and 2007 when larger catches have were obtain in the CAI. The catch in the WAI for 2011 and 2102 increased to 162 t and 168 t, respectively, from the 2004 – 2010 average of 35 t, and the 2013 WAI catch (through July 27) is 132 t. The recent increased shortraker catch in the WAI may reflect the change in the seasonal pattern of target fisheries associated with the closure of the WAI for directed fishing for Atka mackerel and Pacific cod beginning in 2011. Exploitation rates for the WAI have been below M for all years between 2004-2010, but have exceeded 0.75*M (i.e., the level associated with F_{abc} for a Tier 5 stock) in this area since 2011 (Figure 5). Exploitation rates for the EBS have frequently been above 0.75*M (2004-2005, 2010-2011). Large exploitation rates were estimated for the SBS area in 2011 and 2012, resulting from relatively large catches in an area with relatively low survey abundance. However, the CVs for survey biomass estimates for the SBS are typically the largest for any of the subareas (Figure 2).

Population trends

Differential changes in population trends between subareas could reflect stock structure and a lack of connectivity between areas. The available information does not suggest differential trends between the subareas. However, given the high survey CVs in some subareas, any potential trend in the true area biomass may be relatively difficult to observe.

Generation time

Generation time is a characteristic of a species that reflects longevity and reproductive output, with long generation times indicating increased time required to rebuild overfished stocks. The mean generation time (G) was computed as

$$G = \frac{\sum_{a=1}^{A} a E_a N_a}{\sum_{a=1}^{A} E_a N_a} \qquad \text{Eq. 1}$$

where a is age, A is expected maximum age for an unfished stock, N is females per recruit in the absence of fishing, and E is fecundity at age (Restrepo et al. 1998). Because fecundity is unknown, E was replaced by the product of proportion mature and body weight, thus using spawning stock biomass rather than egg production (Restrepo et al. 1998). Maturity data for BSAI shortraker rockfish is not known, so maturity information from McDermott (1994), based primarily on sampling in the Gulf of Alaska from 1991 – 1993, was used, with the proportion mature at length converted to proportion mature at age from growth parameters based on aging of shortraker rockfish from the 2004 and 2006 AI surveys.

It is worth noting that the otoliths collected in the 2004 and 2006 AI trawl survey are the only collections of BSAI shortraker otoliths which been aged, and that the level of between-reader uncertainty in the otolith readings is higher than several other rockfish species. The percent of cases in which two readers assigned the same age to an otolith exceeded 30% for only two ages, and the percent agreement for young fish was approximately the same level as older fish (Figure 6). Other species such as northern rockfish and Pacific ocean perch typically show high percent agreement at young ages, and a reduction in percent agreement with age. The high level of age-reading error for shortraker rockfish should be considered when evaluating age-based metrics such as growth parameters.

The estimated mean generation time for BSAI shortraker rockfish was 56 years. In general, rockfish species would be expected to have large mean generation times due to their longevity; for example, the estimated generation times for BSAI POP and blackspotted/rougheye rockfish were 28 years and 53 years, respectively.

Physical limitations (clear physical inhibitors to movement)

The Aleutian Islands is characterized by deep passes that may limit the movement of shortraker rockfish between Aleutian Islands subareas, with several passes in the central and western AI approaching (i.e., Tanaga Pass, Amchitka Pass, and Buldir Pass) approaching or exceeding 1000 m (Figure 7). Shortraker rockfish have highest survey catch per unit effort in the 300m-500m depth zone, and it is possible that excluding depths greater than 500m from the AI survey has resulted in not sampling a portion of the shortraker population (von Szalay et al. 2011). However, in recent Gulf of Alaska surveys, shortraker rockfish were not observed at depths greater than 700m (von Szalay et al. 2008, 2010). In general, it is expected that traversing the deeper AI passes would require greater utilization of pelagic habitats or deeper depths than currently observed in the Alaska trawl surveys.

Field data on ocean currents can be used to infer the degree of water flow between subareas within the Aleutian Islands. On the north side of archipelago, the connection between the east and west Aleutians is limited due to the break associated with Petral Bank and Bowers Ridge, which results in water flowing away from the Aleutian Islands archipelago (Figure 7, Stabeno et al 2005). On the south side of the Aleutian Islands, the Alaska Stream provides much of the source of the Alaska North Slope Current (ANSC) via flow through Amutka Pass and Amchitka Pass. However, the Alaska Stream separates from the slope west of the Amchitka Pass and forms meanders and eddies, perhaps limiting the connection between the east and west Aleutians.

Although a full discussion of ecological differences between the Aleutian Islands and neighboring areas is beyond the scope of this document, a number of biological and physical measurements suggest that a "biophysical transition zone" (Logerwell et al. 2005) occurs at Samalga Pass. Field observations in 2001-2002 indicate that water west of Samalga Pass was colder, saltier, and more nutrient rich relative to water east of Samalga Pass (Ladd et al. 2005). The passes from Samalga Pass eastward are generally shallow and well mixed by tidal currents, whereas the central and western passes are generally deeper and wider. Hunt and Stabeno (2005) summarize a series of changes that occur west of Samalga Pass, including higher chlorophyll concentrations (Mordy et al 2005), relatively more neritic zooplankton (Coyle 2005), and reduced frequency and abundance of coral (Heifetz et al. 2005). In addition, Logerwell et al. (2005) found a large percentage decline in demersal fish species between Unimak/Samalga and Amutka Passes.

Growth differences

Age data from shortraker rockfish in the Aleutian Island surveys from 2004 and 2006 provide information on size at age within Aleutian Island subarea. Otoliths were obtained by length-stratified sampling, and unbiased estimates of mean length were obtained by multiplying the estimated size composition of the population by the age-length key for that area and year (Kimura and Chikuni 1987; Dorn 1992). The data from both years were grouped together in the analysis. von Bertalanffy growth curves were fit to the mean lengths by assuming the deviations between the model prediction and the observed data follow a normal distribution, and Akaike's Information Criterion (AIC) was used to evaluate whether growth patterns differ significantly between the AI subareas.

The data indicate decreasing size at age from the western AI to the eastern AI (Figure 8). The largest difference in the growth curves was the estimated asymptotic length (L_{inf}), which decreased from 62 cm in the WAI and CAI to 54 cm in the SBS. The resulting von-Bertalanffy growth parameters are as follows:

Area	Fish aged	t_{izero}	K	L_{inf}
WAI	115	-1.39	0.059	61.68
CAI	111	-3.06	0.054	62.15
EAI	101	-1.05	0.069	57.64
SBS	83	-5.65	0.069	54.48

Differences between pairs of subareas can be assessed by differences in AIC (ΔAIC) between a model with a single growth curve for the combined data versus a model with separate growth curves for each subarea. The ΔAIC for all two-way comparisons are shown below; in all comparisons, higher AICs were observed for the simpler model of a single growth curve for the two areas. Using the rule of thumb that ΔAIC <2 indicate substantial support model with the higher AIC, ΔAIC of 3 – 7 indicate considerably less support, and ΔAIC > 10 indicate a very unlikely model (Burnham and Anderson 2002), the data for BSAI shortraker growth indicates little differences between the WAI and CAI area, more substantial differences between the EAI and either the WAI and CAI, and substantial differences between the SBS and each of the other areas.

Area	WAI	CAI	EAI	SBS
WAI		1.28	6.13	30.83
CAI			6.68	27.00
EAI				11.52

Size structure

Given the limited amount of age data, spatial differences in the demographic composition were assessed with size data from the AI survey from 1991 – 2012. An ANOVA was used to test for significant differences in the mean size between areas. For each haul where shortraker rockfish were captured, mean shortraker length was weighted by the relative contribution of the haul (indicted by numerical CPUE) to the estimated population size for the stratum in which the haul occurred.

A plot of mean size and standard deviations by area and year is shown in Figure 9. The mean sizes within the WAI, CAI, and EAI are similar to each other and do not show any consistent patterns over time. The mean sizes in the SBS area are higher in some years (1994-2000, and 2012) than the mean sizes in other areas, but also show higher estimates of standard deviations that reflect that shortraker rockfish were observed in no more than 4 hauls for each year. The mean size in the EBS area (based on data collected in the EBS slope survey) has appeared to increase in recent years, with the average size ranging between 45 – 55 cm for the 2002-2004 surveys, and between 54 – 64 cm for the 2008 and 2012 surveys. The full ANOVA indicated significant effects for year, area, and year*area interaction, with the year effects being largely driven the WAI (higher mean sizes in 2004 and 2006) and the EBS. A simpler ANOVA model which the combined data across years and compared sizes from the AI management subareas (including samples from the WAI, CAI, and EAI subareas) and the BS management subarea (including samples from the SBS and EBS subareas) indicated a significant area effect ($P < 0.001$), with weighted mean sizes of 46 cm in the AI and 55 cm in the BS.

Genetics

Population structure for shortraker rockfish has been observed in studies that have utilized microsatellite DNA (Matala et al. 2004) and mitochondrial DNA (Gharrett 2003), although these studies have largely focused in the north Pacific and have relatively limited sampling within the BSAI area. Samples analyzed for microsatellite DNA were obtained from

Baranof Island to approximately Adak Island and pooled into eight geographically distinct collections. The collection of samples centered near Adak Island comprises the BSAI samples and consists of 186 of the 528 total samples. The microsatellite data indicated population structure at spatial scales consistent with broad management regions (i.e., GOA, AI, and EBS). The most efficient partitioning of the genetic variation into non-overlapping sets of populations identified three groups: a southeast Alaska group, a group extending from southeast Alaska to Kodiak Island, and a group extending from Kodiak Island to the Adak Island (the western limit of the samples) (Figure 10). Although the genetic divergence did not correspond to a geographic pattern of isolation by distance, the analysis did indicate that homogeneity among allele populations was restricted geographically. Matala et al. (2004) conclude that the observed structure may be related to the loci examined and the sample size, and a more comprehensive study may indicate additional structure.

A parallel study using mitochondrial DNA (mtDNA) sampled over the same area and pooled into eight distinct collections (Gharrett 2003). Partitioning the genetic variation into homogeneous groupings indicated three groups with spatial scale similar to that observed with the microsatellite DNA data: a southeast Alaska group, a group extending from the Yakutat area to the Shumagin area, and a group extending from Unimak Island to Adak Island. However, the statistical significance of this grouping was generally weaker (P<0.10), with only the Unimak – Adak Island group supported at the 0.05 level. Numerous haplotypes were observed but one haplotype accounted for 70% of sampled fish, indicating a species that has recently (in evolutionary time scales) expanded from a population bottleneck. Additionally, the geographic distribution of the haplotypes is consistent with restricted gene flow and isolation by distance since the beginning of the population expansion.

Conclusions

There is relatively little information on genetic structure within the BSAI area. One might take the view that no action should be taken until such information was available; however, this would be counter to the SSWG recommendations for dealing with uncertainty. More generally, a common practice in fisheries assessments in handling missing information is to use information from closely related stocks, and this approach has been applied to such processes as maturity, growth, recruitment variation, fishery selectivity, etc. For example, a recommendation of the 2013 rockfish CIE review panel was to apply hierarchical modeling to data-poor rockfish stocks, citing an example approach that assumed commonalities between species with respect to exploitation trends, fishery selectivity, and patterns of recruitment (Punt et al. 2011). Given that a several rockfish stocks in Alaska have shown fairly fine scale structure (northern rockfish, blackspotted rockfish, POP), and that this is consistent with findings for west coast rockfish, it seems reasonable to postulate that rockfish species such as shortraker rockfish with a similar life-history pattern might be expected to show a similar pattern of genetic spatial structure. The difference in estimated growth curves is also consistent with the hypothesis of spatial structuring within the BSAI.

There are five rockfish stocks or stock complexes in the BSAI, and four methods of spatial apportionment, as shown in the table below.

BSAI Stock or Stock Complex	Number of ABCs	Division of ABC
Pacific ocean perch	4	1 each for the WAI, CAI, EAI, and EBS areas.
Other rockfish complex	2	1 for the EBS and AI areas.
Blackspotted/rougheye rockfish	2	1 ABC for combined WAI/CAI area, separate ABC for combined EAI/EBS area
Northern rockfish	1	BSAI-wide ABC
Shortraker rockfish	1	BSAI-wide ABC

The SSWG was created, in part, to help ensure some consistency in the evaluation of stock structure and spatial management. A comment from the 2013 rockfish CIE reviewers was that inconsistencies in spatial management between rockfish species should only be allowed when a clear justification is provided, which has not been the case for BSAI rockfish. This view relies on the assumption, stated above, that closely related rockfish species might be expected to show similar patterns of spatial structure.

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Table 1. Framework of types of information to consider when defining spatial management units (from Spencer et al. 2010).

HARVEST AND TRENDS	
Factor and criterion	Justification
Fishing mortality (5-year average percent of F_{abc} or F_{ofl})	If this value is low, then conservation concern is low
Spatial concentration of fishery relative to abundance (Fishing is focused in areas << management areas)	If fishing is focused on very small areas due to patchiness or convenience, localized depletion could be a problem.
Population trends (Different areas show different trend directions)	Differing population trends reflect demographic independence that could be caused by different productivities, adaptive selection, differing fishing pressure, or better recruitment conditions
Barriers and phenotypic characters	
Generation time (e.g., >10 years)	If generation time is long, the population recovery from overharvest will be increased.
Physical limitations (Clear physical inhibitors to movement)	Sessile organism; physical barriers to dispersal such as strong oceanographic currents or fjord stocks
Growth differences (Significantly different LAA, WAA, or LW parameters)	Temporally stable differences in growth could be a result of either short term genetic selection from fishing, local environmental influences, or longer-term adaptive genetic change.
Age/size-structure (Significantly different size/age compositions)	Differing recruitment by area could manifest in different age/size compositions. This could be caused by different spawning times, local conditions, or a phenotypic response to genetic adaptation.
Spawning time differences (Significantly different mean time of spawning)	Differences in spawning time could be a result of local environmental conditions, but indicate isolated spawning stocks.
Maturity-at-age/length differences (Significantly different mean maturity-at-age/ length)	Temporally stable differences in maturity-at-age could be a result of fishing mortality, environmental conditions, or adaptive genetic change.
Morphometrics (Field identifiable characters)	Identifiable physical attributes may indicate underlying genotypic variation or adaptive selection. Mixed stocks w/ different reproductive timing would need to be field identified to quantify abundance and catch
Meristics (Minimally overlapping differences in counts)	Differences in counts such as gillrakers suggest different environments during early life stages.
Behavior & movement	
Spawning site fidelity (Spawning individuals occur in same location consistently)	Primary indicator of limited dispersal or homing
Mark-recapture data (Tagging data may show limited movement)	If tag returns indicate large movements and spawning of fish among spawning grounds, this would suggest panmixia
Natural tags (Acquired tags may show movement smaller than management areas)	Otolith microchemistry and parasites can indicate natal origins, showing amount of dispersal
Genetics	
Isolation by distance (Significant regression)	Indicator of limited dispersal within a continuous population
Dispersal distance (<<Management areas)	Genetic data can be used to corroborate or refute movement from tagging data. If conflicting, resolution between sources is needed.
Pairwise genetic differences (Significant differences between geographically distinct collections)	Indicates reproductive isolation.

Table 3. Summary of available data on stock identification for BSAI shortraker rockfish.

HARVEST AND TRENDS	
Factor and criterion	Available information
Fishing mortality (5-year average percent of F_{abc} or F_{ofl})	Recent catches in the BSAI are approximately ½ the ABC level.
Spatial concentration of fishery relative to abundance (Fishing is focused in areas << management areas)	Estimated exploitation rates in the the EBS slope area have frequently exceeded 0.75*M since 2004, whereas exploitation rates in the WAI have exceeded 0.75*M from 2011-2013.
Population trends (Different areas show different trend directions)	Population trends do not appear to be different between areas, although the uncertainty of the survey data in the subareas increases with smaller sample sizes.
Barriers and phenotypic characters	
Generation time (e.g., >10 years)	The generation time is approximately 56 years
Physical limitations (Clear physical inhibitors to movement)	The Aleutian North Slope Current does not extend west of the central AI, limiting the connections within the AI. Also, studies of the AI ecosystem indicate a "biophysical transition zone" at Samalga Pass (Logerwell et al. 2005)
Growth differences (Significantly different LAA, WAA, or LW parameters)	Significantly different growth curves were observed between the BSAI subareas, with lower length at age in the SBS and EAI areas than in the WAI and CAI areas.
Age/size-structure (Significantly different size/age compositions)	Mean size is larger in the EBS slope than in the Aleutian Islands
Spawning time differences (Significantly different mean time of spawning)	Unknown
Maturity-at-age/length differences (Significantly different mean maturity-at-age/ length)	Unknown
Morphometrics (Field identifiable characters)	Unknown
Meristics (Minimally overlapping differences in counts)	Unknown
Behavior & movement	
Spawning site fidelity (Spawning individuals occur in same location consistently)	Unknown
Mark-recapture data (Tagging data may show limited movement)	Mark-recapture data not available
Natural tags (Acquired tags may show movement smaller than management areas)	Unkown
Genetics	
Isolation by distance (Significant regression)	Significant pattern of isolation by distance.
Dispersal distance (<<Management areas)	Dispersal distances have not been estimated
Pairwise genetic differences (Significant differences between geographically distinct collections)	Significant pairwise differences between sets of genetic samples in the north Pacific, with sampling primarily focused in the Gulf of Alaska.

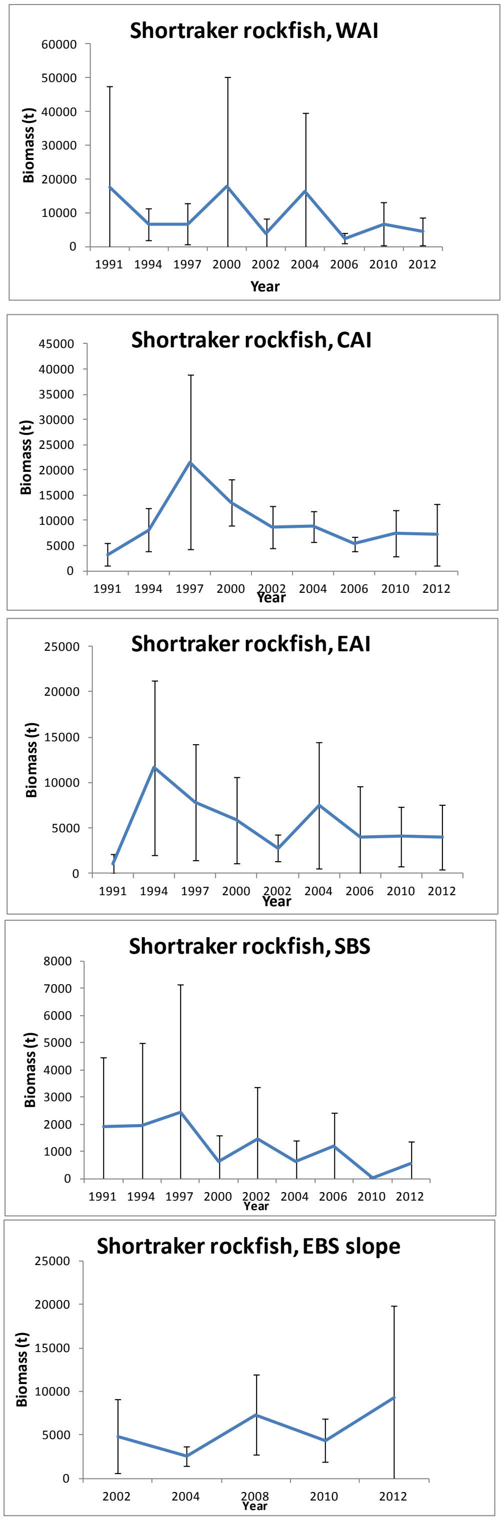

Figure 1. Shortraker rockfish survey biomass estimates from the Aleutian Islands and eastern Bering Sea slope surveys.

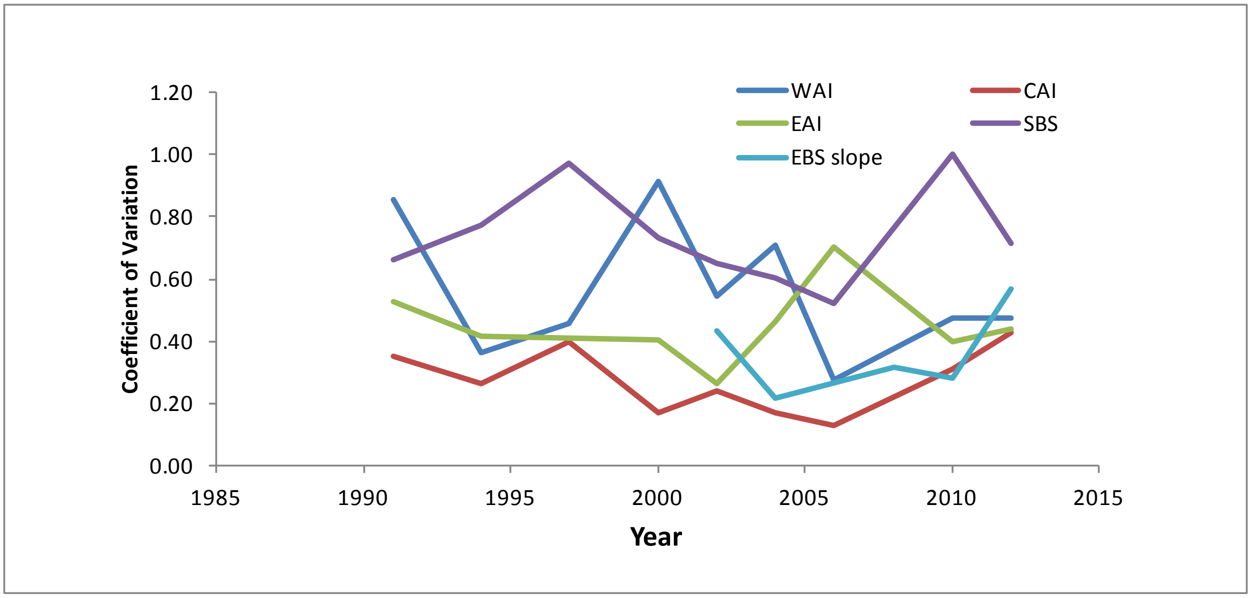

Figure 2. Coefficients of variation (CV) for rockfish biomass estimates from the Aleutian Islands and EBS slope surveys.

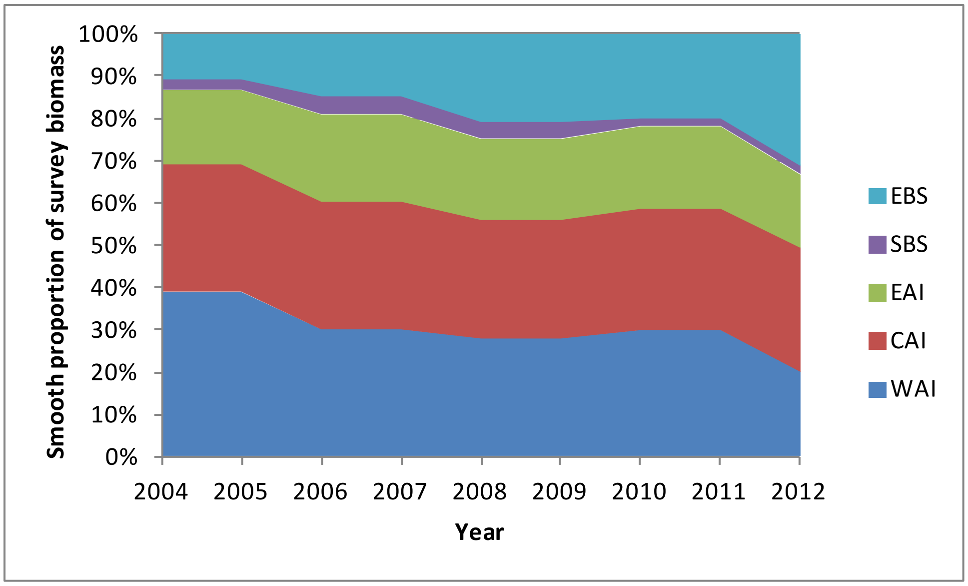

Figure 3. Estimated proportions of shortraker rockfish biomass by subarea within the BSAI area from 2004-2012. For each year, the proportions were computed from weighted averages of the three most recent Aleutian Islands and EBS slope survey.

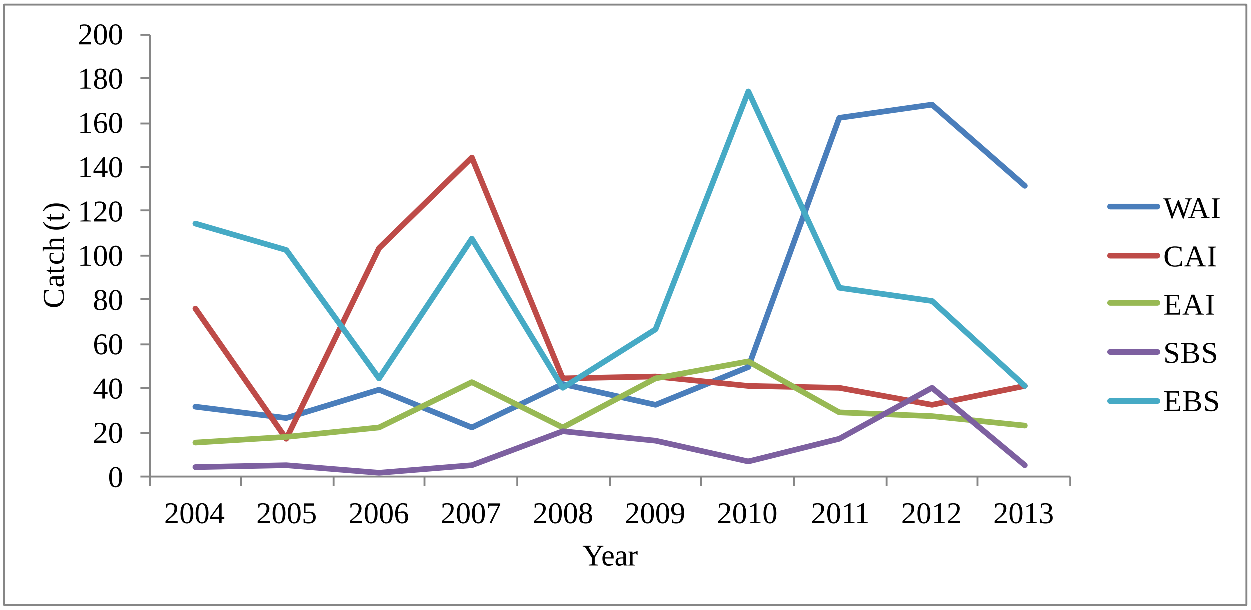

Figure 4. Catch (t) of shortraker rockfish by BSAI subarea, 2004-2013; 2013 data is through July 27.

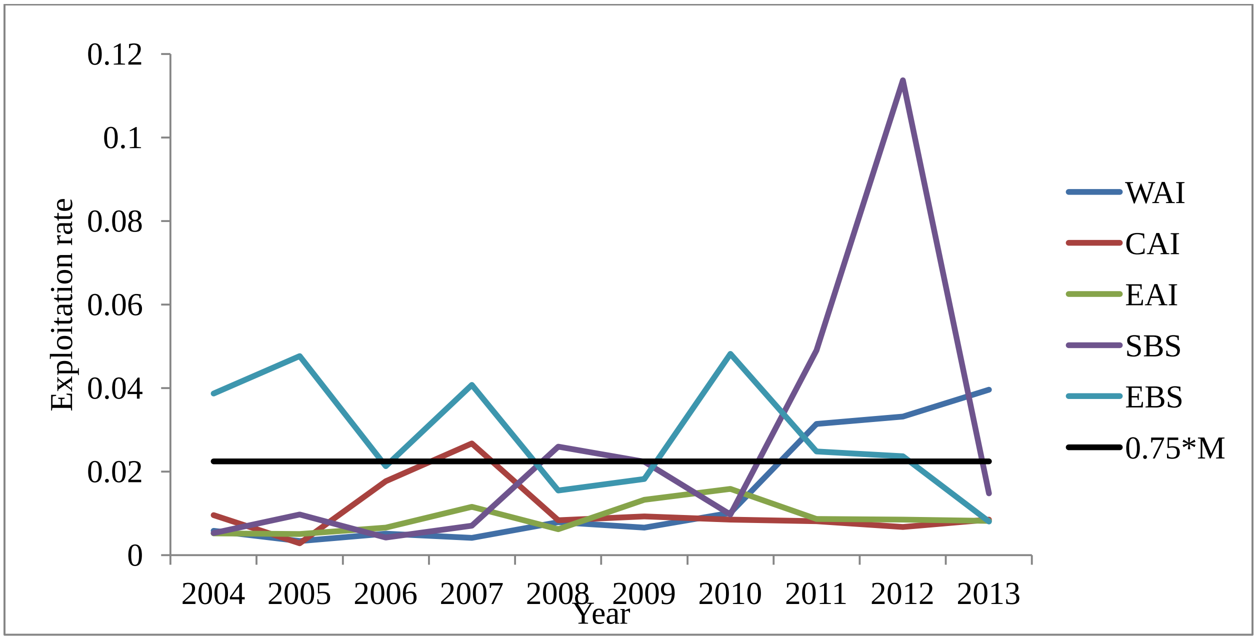

Figure 5. Estimated shortraker rockfish exploitation rates by area from 2004-2013, with 2013 rates based on catches through July 27.

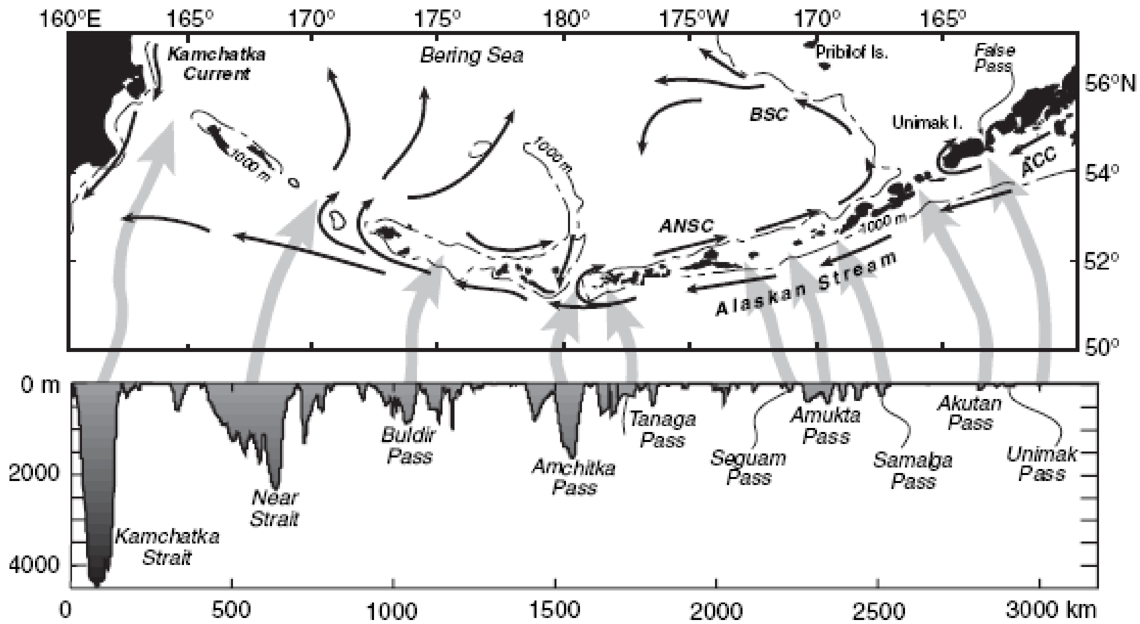

Figure 6. Schematic of ocean currents in the Aleutian Islands, showing the Alaska Steam, the Alaska Coastal Current (ACC), and the Aleutian North Slope Current (ANSC) (from Stabeno et al. 2005). The lower panel shows the location and depth of ocean passes in the Aleutian Islands archipelago.

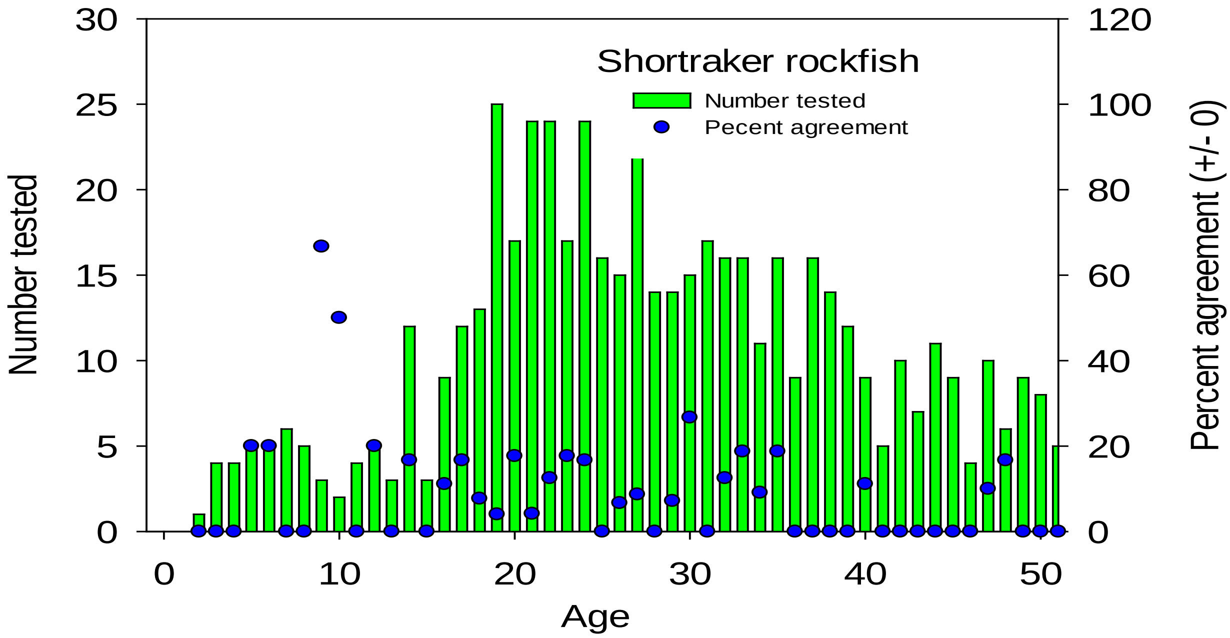

Figure 7. Between-reader agreement of shortraker rockfish age readings and number of shortraker rockfish tested (Dr. Tom Helser, AFSC, pers. comm.)

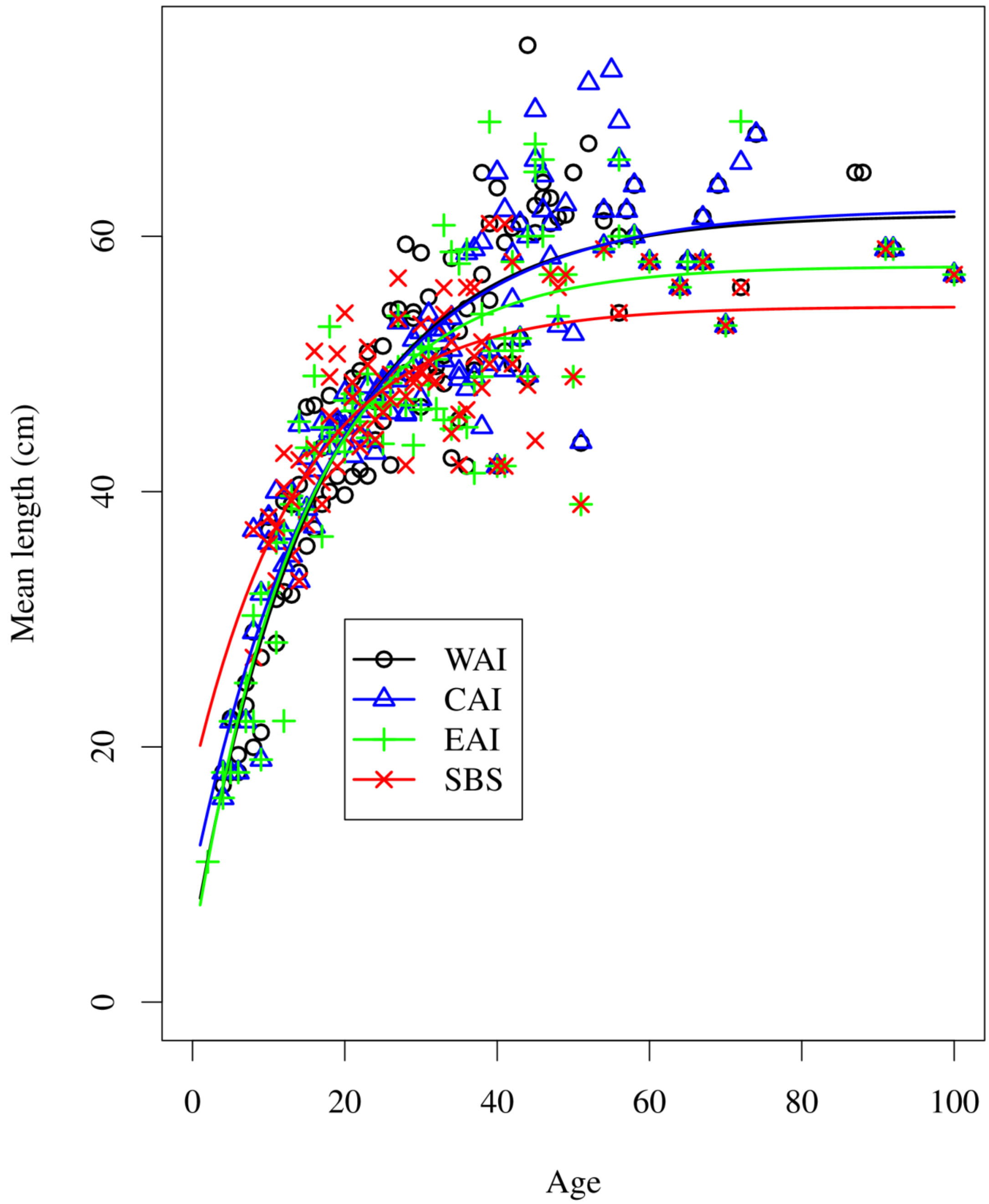

Figure 8. Estimated area-specific growth curves for shortraker rockfish, based Aleutian Islands survey data from 2004-2006.

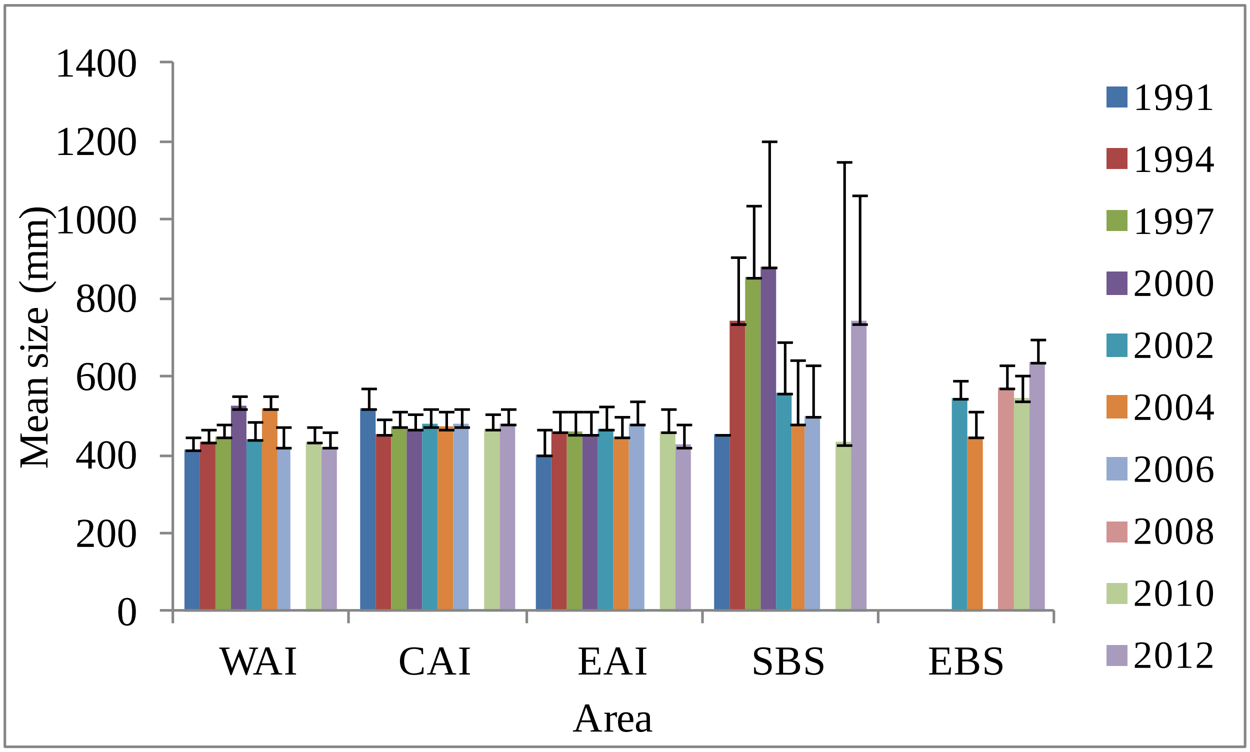

Figure 9. Mean size of shortraker rockfish by BSAI subarea and year in from Aleutian Island and EBS slope trawl surveys; error bars are 2x the standard deviation.

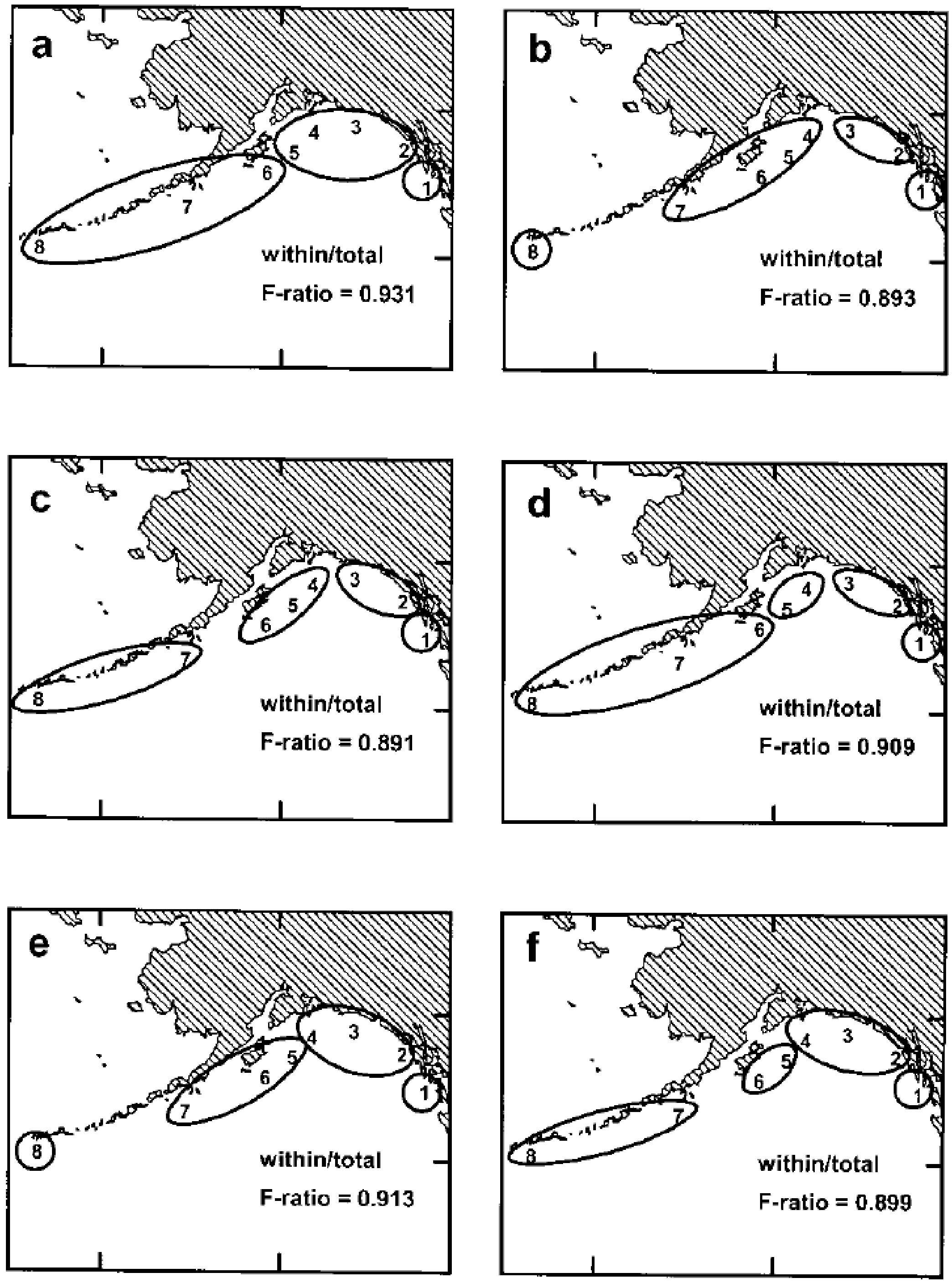

Figure 10. Sample location for analysis of shortraker rockfish microsatellite DNA, with F-ratio that indicate the ratio of within-group genetic variation to total genetic variation. Population groups that resulted in the highest F-ratio indicate the most efficient partitioning of genetic variation, and is shown in panel (a). (Figure from Matala et al. 2004)